Paper

Telecommunications, multiple criteria analysis and knowledge theory

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Abstract— Telecommunications requires multiple criteria analysis and decision support. It is shown how some basic facts from telecommunications and informational sciences can be used to formulate a rational theory of intuition, developed as a complement of multiple criteria decision support. This paper presents a method called creative space used for integrating various approaches to knowledge creation and based on SECI spiral, I^5 system and rational theory of intuition. Questions of supporting new technology creation by constructing specialized creative environments similar to decision support environments are also indicated.

Keywords— decision support, intuition, knowledge creation, knowledge integration and management, tacit knowledge, ontology and epistemology, technology creation, telecommunications.

1. Introduction

We can list diverse problems from telecommunications that need formulation with multiple criteria: in network design, in routing, in telecommunication data mining, in interconnection agreements, in strategic management of telecommunications. However, telecommunications and other informational sciences influence also our way of understanding the world in the new civilisation era of informational and knowledge-based economy. This understanding is systemic and chaotic, assumes the emergence of qualitatively new properties of complex systems which cannot be reduced to the properties of system components. On this background, it is necessary to reflect anew on the theory of knowledge.

In fact, multiple criteria decision support developed, during several decades of research, methodologies that are useful in knowledge representation and creation today. During the last decade of 20th century, several new approaches explaining knowledge creation processes were published. The first of them, Shinayakana systems approach of Nakamori and Sawaragi [21], originated in multiple criteria decision support. Much better known become another approach, originating in management science, the knowledge creating company with SECI spiral process of Nonaka and Takeuchi [24]. Several other approaches were developed and published parallel; this signified a paradigmatic change in epistemology.

2. Telecommunications and decision support versus knowledge creation

Telecommunications becomes today naturally integrated with other informational technologies. Telecommunication networks not only offer more intelligent services, but also require the use of computer intelligence and other advanced informational civilization tools, such as multiple criteria decision support, for being effectively designed, managed and developed strategically. Diverse problems from telecommunications need formulation with multiple criteria. In fact, network design is an essentially multiple criteria decision process. Routing problems have been traditionally solved by assuming *ad hoc* scalarized aggregation of multiple criteria; recently, it is becoming recognized that we must use many criteria in routing and explicitly discuss the questions how to aggregate them. Related techniques of decision support, such as data mining, are increasingly developed and used in telecommunications, simply because the amount of data available concerning the functioning of telecommunication networks is tremendous. Decision support techniques become needed when solving strategic management problems in telecommunications, such as problems related to interconnection agreements that require multiple criteria negotiation techniques.

On the other hand, during several decades of research multiple criteria decision support developed specific methods that are useful in knowledge representation and creation today. For example, *model based decision support* [39] distinguishes between *preference model* and *substantive* or *core model* of the decision situation; while the former represents information about the preferences of the decision maker, the latter represents a synthesis of knowledge about the essential aspects of the decision situation, independent of the decision maker preferences. Thus, mathematical modeling in decision support is used today in order to create *virtual laboratories*, to *represent and organize knowledge* [40].

The advances of computerised decision support, in particular related to vector optimisation and multiple criteria decision making, contributed also to the concept of user sovereignty – the sovereign role of the user of computerised decision support (e.g., [39]). This concept is also related to the assumption that human mind is capable of information processing ways as yet not duplicated by computers. This assumption and the reflection on applications of multiple criteria decision support resulted in *Shinayakana* *systems approach* of Nakamori and Sawaragi [21] as well as in formulation of a *rational theory of intuition* [37]; as we shall show later, this theory utilizes basic knowledge from telecommunications. In turn, a reflection on the needs of the beginnings of the new civilisation era of information and knowledge-based economy shows that multiple criteria decision making and the resulting rational explanation of human intuition are closely related to new developments in knowledge theory and that a new understanding of knowledge theory is necessary for the new era.

Moreover, we could use diverse methods developed for criteria aggregation in multiple criteria decision support also for synthesizing and aggregating knowledge. Thus, methods of decision support could naturally evolve into methods of knowledge integration and creativity support. These possibilities are the subject of research at the JAIST 21st Century Center of Excellence (COE) Program *Technology Creation Based on Knowledge Science*, in which scientific and technical development strategies can be formulated in cooperation with outside research organizations. At the same time, the COE contributes to the development of an education system that will demonstrate the synergetic effect of combining diverse disciplines and fields. The COE offers an advanced model of setting research priorities for three JAIST graduate schools: Information Science, Material Science and Knowledge Science. However, before commenting further on the possibility of such developments we must become aware of contemporary developments in knowledge theory.

3. New approaches to the problem of knowledge and technology creation

Historically, we could distinguish two main schools of thinking how knowledge is created.

The first school maintained that knowledge creation is essentially different activity than knowledge validation and verification, and distinguished *the context of discovery* from *the context of verification*. This school also maintained that creative abilities are irrational, intuitive, instinctive, subconscious. Such opinion was supported by many great thinkers of very diverse philosophical persuasions and disciplinary speciality. Nietzsche, Bergson, Poincare, Brouwer, Einstein, Heisenberg, Bohr, Freud, Jung, Popper, Kuhn, Polanyi were all characterizing creative abilities in such a way, although every one of them stressed different aspects of this general view.

The second stream kept to the old interpretations of science as a result of induction and refused to see creative acts as irrational. This view, represented by many hard scientists, is popular particularly in English-speaking world[1]. This view is represented also by recent works (e.g., [31]), a book rich in historical data on creativity, but refusing to analyze subconscious or unconscious aspects of creative acts. However, since the last decade of 20th century quite new approaches to knowledge creation appeared, related to these subconscious or unconscious aspects, to the concepts of tacit knowledge, of intuition and of group collaboration, most directly or indirectly related to Japanese origin.

The first of such approaches, *Shinayakana systems approach* of Nakamori and Sawaragi [21], originated in the field of multiple criteria decision support. It did not specify a process-like, algorithmic recipe for knowledge and technology creation, only a set of principles. To these principles belong: using intuition, keeping open mind, trying diverse approaches and perspectives, being adaptive and ready to learn from mistakes, being elastic like a willow but hard as a sword (*Shinayakana*).

Parallel, in management science, another approach was developed by Nonaka and Takeuchi in the book *The Knowledge Creating Company* [24]. This is the now renowned SECI spiral, with a process-like, algorithmic principle of organizational knowledge creation. This principle is revolutionary for western epistemology because it utilizes not only the collaboration of a group in knowledge creation, but also the rational use of irrational (or a-rational to a Japanese) mind capabilities, namely tacit knowledge consisting of emotions and intuition. The SECI spiral results from four consecutive transitions between four nodes on two axes. One is called *epistemological dimension* including *tacit* and *explicit knowledge*; the other is called *ontological dimension*[2] and includes *individual* and *group*. The transition from individual tacit knowledge to group tacit knowledge is called *socialization*, consists of social exchange of ideas; the transition from group tacit to group explicit – *externalization*, consists in writing down and codifying the ideas; the transition from group explicit to individual explicit – *combination*, consist in combining individual knowledge with the ideas generated by the group; the transition from individual explicit to individual tacit – *internalization*, consists in applying new knowledge in practice and thus increasing tacit (actually, intuitive) knowledge. Knowledge is increased after each such cycle, thus the name SECI spiral expresses increasing knowledge in spiral repetition.

But the problem of using irrational or a-rational mind abilities rationally was at this time perceived also by other researchers, in particular in Poland. Starting from interactive decision support, Wierzbicki published the *rational theory of intuition* [37], influenced by the formation of Shinayakana systems approach while spending a year at Kyoto University in 1990. We shall present an outline of this theory in a further part of the paper. Soon afterwards, from the mainstream of philosophy, Motycka [19] proposed another

[1]Perhaps because of the unfortunate property of English language that understands the word *science* in the sense *hard sciences*, excluding *technology*, but also excluding *soft and human sciences* – sociology, economics, law, history, etc. Other languages – such as German, Polish, Japanese – understand the word *science* more broadly and we, speakers of these languages, are prepared for the opinion that creative acts are irrational.

[2]Since also tacit and explicit knowledge are ontological elements of discourse, we shall use here rather the name *social dimension*. We also use here *transition* instead of original *knowledge conversion*, because transition indicates changing point of attention while conversion indicates transforming and using up a resource, while knowledge is a special resource that is not used up when used.

theory, this time of basic knowledge creation. She used for this purpose also irrational abilities of human mind – *instincts and myths*, not intuition, namely the concept of *collective unconscious* of Jung [12]. She postulates that, in times of a crisis of a basic science, scientist use a *regress* to myths and instincts in order to obtain stimulation of novel approaches to their field of science. These two Polish approaches were developed independently from SECI spiral, though influenced by Japanese tradition – Wierzbicki directly by Shinayakana systems approach, Motycka by Jung, and thus indirectly by Freud, Nietzsche.

A few years after international publication of the book *The Knowledge Creating Company* [24], several approaches directly stimulated by this book were also published, including several papers presented at the 37th Hawaiian International Conference on Systems Science in Hawaii 2004. For example, Gasson [9] observed that a Western company would use a process very much resembling SECI spiral but moving in opposite direction.

Further development of Shinayakana systems approach was given by Nakamori [22] in a systemic and process-like approach to knowledge creation called I^5 *system* or *Nakamori pentagram*. Five ontological elements of this system are *intelligence* (and existing scientific knowledge), *involvement* (and social motivation), *imagination* (and other aspects of creativity), *intervention* (and the will to solve problems), *integration* (using systemic knowledge). There is no algorithmic recipe (true to *Shinayakana* tradition) how to move between these nodes. Thus, I^5 *system* stresses the need to move freely between diverse dimensions of creative space.

There is no doubt that, since the beginning of the last decade of 20th century, many approaches were developed stressing and rationalizing the need of using irrational abilities of human mind in creative processes. It is, actually, a scientific revolution, because the philosophy of 20th century (explicitly in the first half of century, tacitly in the second half) was dominated by the principles of logical empiricism that refused to speak about such metaphysical aspects. We interpret this revolution as one of the indications of a new informational and knowledge civilization era.

4. Changing understanding of the world at the beginning of knowledge civilization era

The nature of the current *global information revolution* is described by various perceptions, diagnoses and concepts, but it is generally accepted that new *global information infrastructure* will gradually result in *knowledge-based economy* and in *information society* or even in *networked informational civilization*. Castells [4] rightly argues that we should use the term *informational society* rather than *information society* and that an appropriate concept is *networked society*. These ideas are augmented by the concept of *knowledge-based economy* and by disputes about the similarities and differences between the concepts of *information* and *knowledge*; thus, we might rather speak today about *informational and knowledge-based* civilization era, shortly *knowledge civilization era*.

Knowledge civilization era will be a long duration historical structure in the sense of Braudel [3], who considered such structure between the years 1440 (the rediscovery of print by Gutenberg) to 1760 (the improvement of the discovery of steam engine by Watt). Industrial civilization lasted approximately from 1760 until 1980 and informational civilization will probably last from 1980 (the combination of two earlier discoveries of computer and telecommunication networks, enabling broad social use of informational technology) until the end of 21st century (see [36, 38]). Braudel defined a long duration historical structure as a historical era in which basic ways of understanding the world are relatively stable.

In such diverse interpretations and approaches to the current information revolution, there is also a common basis. There is no doubt that *information and knowledge are becoming essential economic assets* with either private or public character and that it is necessary to develop both rules of their sharing and business models of their selling and exchange. However, not many people understand fully the informational civilisation, many see only its technological aspects or are afraid of diverse threats brought by it. To help in its understanding, the following structural model of informational civilization in the form of its three basic megatrends was proposed in [38]. These megatrends are the following.

- The technological *megatrend of digital integration* (or *convergence*). Since all signals, measurements, data, etc., might be transformed to and transmitted in a uniform digital form, we observe today a long-term process of integrating various aspects of information technology. Telecommunication and computer networks are being integrated. Diverse aspects of intelligence of networks and computers are becoming integrated. Diverse communication media are becoming integrated and there are economic and political fights who will control them. Formerly diversified information technologies – telecommunications, informatics, automatic control, electronic engineering – are becoming integrated, etc. This megatrend will define for many years yet the directions of information technology change.
- The social *megatrend of change of professions* (*of dematerialization of work*). The information technology, the automation of heavy work result together slowly in a de-materialization of work. This, however, induces a rather rapid change of existing professions; in industrial age it was sufficient to learn a profession for entire life, now we must re-learn several times in life. Some old professions disappear, others are essentially changed. The speed of this change is limited by socio-economic factors; technology would permit to build fully automated, robotic

factories even today, but what we shall do with the people that work in existing factories? Since not all people are equally adaptable, this megatrend results in the *digital divide* – on those who can speedily learn and profit from information technology and those who are excluded from this technological progress; this is accompanied by *generational divide*. The digital and generational divide affects and concerns not only people in one country, also diverse countries. These divides can threaten the existence of democratic society and market economy as we know them now. Thus, it is essential to find ways to alleviate the effects of digital and generational divide and, in particular, to devise new professions, new occupations for people in replacement of the old professions and occupations.

- The intellectual *megatrend of mental challenges, of changing the way of perceiving the world*. The perception of the world in industrial society was mechanistic, the world was perceived as a giant mechanism – *a clock turning with the inevitability of celestial spheres*. This resulted, on one hand, in the reduction principle described above, on the other hand, in the dominating belief in *inevitability*. For all specific differences, this belief motivated equally Kant (his *categorical imperative*, the transcendental moral principle *inevitably* follows logical reflection on the moral rights of fellow humans), Smith (the invisible hand of the market expresses *inevitability*) and Marx (with his *inevitability* of laws of history). Such a way of perceiving the world is still predominating (see, e.g., *The End of History* of Fukuyama [7]) and its change will be very difficult and will take time. However, it is very important to understand the change towards *systemic and chaotic way of perceiving the world, which will be typical for informational civilization*.

There are two basic concepts that were developed because of mathematical modeling that exceeded its domain and contributed essentially to the change of perceiving the world typical for the beginnings of a new civilization era. These are the concepts of *chaos* and *complexity*.

We needed to simulate random numbers in a digital computer that is an essentially deterministic device; thus, we quite early discovered the principle of a quasi-random number generator that today would be called a chaotic generator of a strange attractor type. Although this is not stressed in the typical publications on the deterministic theory of chaos (see, e.g., [10]) the quasi-random generators in digital computers were the first practical applications of the theory, preceding in fact the development of the theory. The principle of such a generator exemplifies in fact the basic principles of a strange attractor: take a dynamic system with strong nonlinearity and include in it a sufficiently strong negative feedback to bring it close to instability – or, in discrete time, apply recourse.

For specialists in mathematical modeling of nonlinear systems *there is nothing strange in strange attractors, in order emerging out of chaos, in emergence of essentially new properties* because of the complexity of the system. Order can emerge also from probabilistic chaos, as stressed by Prigogine [29]. The principle of order emerging from a probability distribution is mathematically rather simple: a strongly nonlinear transformation of a probability distribution can result in amplifying the probability of selected events, thus eventually in order.

This was only a *rational justification* of the principle of emergence, *justified also empirically* by earlier observations in nature, e.g., by biology in the concept of punctuated evolution. Additionally, technology and especially telecommunications provided a third type, *pragmatic justification*: in complex technological systems we construct today, complexity could not be mastered without assuming that higher layers of complexity require concepts irreducible to the properties of lower layers. For example, in the ISO-OSI seven layers stack of protocols of teleinformatic networks (computer networks), the functions and properties of higher layers, e.g., the highest *layer of applications*, are independent, irreducible, thus in a sense transcendental to the functions and properties of lower layers, e.g., the lowest *physical layer*.

Therefore, we can say that *biology*, but also *systems science, mathematical modeling, informational and telecommunications technology prepared a fundamental change of the way we perceive the world today*. The science of industrial civilization era perceived the world as a system explained by the behavior of its elementary parts or particles. This *reduction principle – the reduction of the behavior of a complex system to the behavior of its parts* – is valid only if the level of complexity of the system is rather low. With very complex systems today, systems science, biological but also technical and informational sciences adhere rather to *emergence principle – the emergence of new properties of a system with increased level of complexity, qualitatively different than the properties of its parts*.

We should add that the concept of complexity is used above only in its general, qualitative sense, while mathematical modeling and information sciences today developed a specific, quantitative-qualitative *theory of computational complexity*. This theory describes – qualitatively but in quantitative terms – how the computational effort needed for solving a given type of data processing or operational research problem depends on the dimension of the problem. The main conclusion of this theory is that such dependence is very seldom linear, polynomial only for rather simple problems, highly nonlinear – exponential or combinatorial – for most complicated problems.

5. The rational theory of intuition

We stress here that we are interested in intuition not as a mystic, irrational force, opposed to rationality and objectivity, which is fashionable sine at least one hundred years, even today. We are seeking a *rational explanation* of intuition as a basic creative force, necessary in times of knowledge-based economy and civilization. By *rationality* we understand here not the economic rationality of decisions, but a comprehensive rationality of a scientific theory that combines rationalism, empiricism and falsificationism, thus is close to Quine [30] and Popper [27]: a theory is rational, if it is rationalist (can be deductively derived from some abstract principles), but also empirically viable (corresponds *at its edges* to observed facts) and can be falsified with the help of an experiment or at least allows for practical conclusions that can be tested.

A rational theory of intuition can be considered as a contradiction in terms, because we tend to use the word *intuitive* with some connotation of *irrational* in everyday language. There is a long tradition of such usage of this word (see, e.g., [1]) who attached a great importance to intuition but interpreted it as a mystic force, which by definition could not be a subject of rational means of inquiry. After a century, even today *we do not want to make intuition rational, we want only to explain its functioning in rational terms*; however, we stress that such an explanation is not only possible, it is necessary.

First element of the rational theory of intuition is based on contemporary knowledge – from the field of computational complexity and telecommunications – about relative complexity of processing audio and video signals. The ratio of bandwidth necessary for transmitting audio and video signals is ca 1:100 (20 kHz to 2 MHz). Let us assume conservatively that the increase of the complexity of processing these signals (for similar purposes, such as word and picture recognition) is rather mild, say quadratic – the simplest and one of the mildest of nonlinear increases in computational complexity. Then we obtain the lower bound for the ratio of computational complexity of at least 1:10 000. Thus, the old proverb *a picture is worth one thousand words* is not quite correct: *a picture is worth at least ten thousand words*. Naturally, human mind processes signals in a different way than a digital computer, with elements of analog processing and much higher degree of parallelism, distribution, redundancy; and human vision is much better than television. However, these arguments only strengthen the estimation of such a lower bound of processing difficulty that is rather independent of the actual structure of processing device. Anyway, we need further only a qualitative conclusion that processing of visual signals (together with signals from all other human senses) is qualitatively, much more complex than processing speech.

The second element of this theory is a *dual thought experiment*. The technique of a thought experiment was suggested by T. Kuhn [14] who has shown that basic concepts applied in any scientific theory include deep, often hidden assumptions. The best way to examine consistency of such assumptions is not necessarily through empirical experiments, because more enlightening might be thought experiments. Kuhn used such technique for clarifying epistemological assumptions of historical scientific discoveries. Here we use such technique also in historical context, but in order to clarify essential aspects of modern ontology and epistemology, hence we suggest the name *dual* thought experiment.

This experiment consists in considering the question: *how people processed the signals from our environment just before the evolutionary discovery of speech*? They had to process signals from all our senses holistic, though dominant in received information was the sense of sight. Yet they were able to overcome this difficulty, developed evolutionary a brain containing $10^{11} - 10^{12}$ neurons. We still do not know how we use full potential of our brain – but it was needed evolutionary, hence probably fully used before the discovery of speech. We know that the brain processes signals with a great degree of parallelism and distribution, certainly uses neuron networks – though much more complicated than contemporary artificial neural networks – and in a holistic processing of signals uses rather fuzzy than binary logic. Biological research on real neurons shows that an appropriate model of a neuron should be dynamic and nonlinear, with extremely complex behavior. Thus, to model a neuron well we would need the computational capability of a contemporary personal computer, not a single digital switch nor a sigmoid function (the latter being used in contemporary artificial neural networks to represent a single neuron). We conclude that human brain is clearly much more complex than digital computers, though it also processes signals, only in a much more general sense[3].

Reflecting on the dual thought experiment we realize that the discovery of speech was an excellent evolutionary shortcut, we could process signals 10^4 times simpler. The use of speech for interpersonal communication enabled the intergenerational transfer of information and knowledge, we started to build up the cultural and intellectual heritage of mankind, the *third world* of Popper. The biological evolution of people slowed down and eventually stopped – including the evolution of our brains, since we discovered 10^4 times redundancy – but we accelerated intellectual and civilization evolution. Many biologists wonder *why* our biological evolution has stopped. We think that the dual though experiment described here gives a convincing explanation why it happened.

As all simplifications, this had also disadvantages. Seeking better ways of convincing other people, we devised the principle of excluded middle and thus binary logic. An argument of the type: *this must be true or false, there is no third way*, is actually an ideological or political persuasion. Binary logic contributed of course also to tremendous civilization achievements, the construction of computers and computer networks, but it still biases our way of understanding the world. The best example of this bias is *cognitivism* – the conviction that all cognitive processes – including perception, memory and learning – are based on a language-like medium, on a *language of*

[3]Searle [32] argues that human mind does not process signals, but he proves (rightly) that human mind does not process *digital* signals.

thought (see, e.g., [6, 8]) and thus functioning of mind can be modeled as the functioning of a giant computer. Note that cognitivism is a simplification to the same degree as language is a simplification of the original capabilities of our mind.

But language is only a code, simplifying the processing of information about the real world at least 10^4 *times*; therefore, each word must have many meanings, and to clarify our meaning we have to devise new words. By multiplying words, we gradually describe the world more precisely, but we faster discover new aspects of an infinitely complex world – e.g., the *microcosmic* or *macrocosmic* aspects – than we succeed in creating new words.

Our knowledge must be expressed in language, if only for interpersonal verification; since language is only an imperfect code, then *an absolutely exact, objective knowledge is not possible – not because human knowing subject is imperfect, but because he uses imperfect tools for creating knowledge, starting with language*. This fact was not seriously considered by the entire philosophy of 20th century that concentrated on language – starting with logical empiricism and ending with constructivism and postmodernism.

However, what happened to our original capabilities of holistic processing of signals – we might call them *preverbal*, since we had them before the discovery of speech? An alternative description would be *animistic*, but we had a brain greater then most animals even before discovering the speech. The discovery of speech has stopped the development of these abilities, pushed them to the subconscious or unconscious. Our conscious ego, at least its analytical and logical part, identified itself with speech, verbal articulation. Because the processing of words is 10^4 times simpler, our verbal, logical, analytical, conscious reasoning utilises only a small part of the tremendous capacity of our brain that was developed before the discovery of speech. However, the capabilities of preverbal processing remained with us – *but lacking better words, we call them intuition*, and not always know how to rationally use them.

These fundamentals of a rational theory of intuition can be now subject to first empirical validation tests. Let us we *define intuition as the ability of preverbal, holistic, subconscious* (*or unconscious, or quasi-conscious*)[4] *processing of sensory signals and memory content, left historically from the preverbal stage of human evolution*. Let us call this definition *an evolutionary rational definition of intuition*. Let us conclude that *intuitive abilities should be associated to a considerable part of the brain*. Then this should be noted in the research on the structure of brain, on neurosurgery, etc.?

And it was noted – for example, by the results of studies on the hemispherical asymmetry of the brain (see, e.g., [34]). These results suggest that a typical left hemisphere (for right-handed people; for left-handed we can observe the reverse role of brain hemispheres) is responsible for *verbal, sequential, temporal, analytical, logical, rational* thinking, while a typical right hemisphere is responsible for *nonverbal, visual, spatial, simultaneous, analog, intuitive* (!!!). In the results of such research, rational and intuitive types of thinking are typically counterpoised, following the tradition of Bergson [1]; we can accept this opposition of concepts, because *we do not maintain that intuition is equivalent to rational thinking, we only propose a rational explanation and theory of intuition*. Already in 1983, Young [42] defined intuition as the activity of the right hemisphere of the brain. However, Young's definition does not lead to a fully rational theory; we cannot conclude from it, for example, how to stimulate and better use intuition. On the other hand, we can draw such conclusions – among diverse others – from the evolutionary rational definition of intuition. To illustrate such diverse possibilities let us note the following conclusion from this definition: *memory related to intuitive thinking should have different properties than memory related to rational thinking*. And it has – modern research on the functioning of memory (see, e.g., [35]) shows that the phase of deep memorisation occurs during sleep, when our consciousness is switched off.

Each man makes everyday many intuitive decisions of quasi-conscious, operational, repetitive character. These are learned decisions: when walking, a mature man does not have to articulate (even mentally) the will to make next step. Intuitively we pass around a stone on our way, intuitively we turn the key when leaving flat, turn off the alarm-clock after waking, etc. These quasi-conscious *intuitive operational decisions* are such simple and universal that we do not attach any importance to them. But we should study them in order to better understand intuition. Note that their quality depends on the level of experience. We rely on our operational intuition, if we feel well trained. Dreyfus *et al.* [5] show experimentally that the way of decision making depends critically on the level of experience: it is analytical for beginners and deliberative or intuitive for masters.

Now there comes a critical question: *does consciousness help, or interfere with good use of master abilities? If intuition is the old way of processing information, suppressed by verbal consciousness, then the use of master abilities must be easier after switching off consciousness*. This theoretical conclusion from the evolutionary rational definition of intuition is confirmed by practice. Each sportsman knows how important is to concentrate before competition. Best concentration can be achieved, e.g., by Zen meditation practices, which was used by Korean archers before winning Olympic competition.

We suggest that *this theoretical conclusion is also applicable for creative decisions* – such as scientific knowledge creation, formulating and proving mathematical theorems, new artistic concepts. Creative decisions are in a sense similar to strategic political or business decisions. They are usually non-repetitive, one-time decisions. They are usually deliberative – based on attempt to reflect on the whole

[4]Quasi-conscious action can be defined as an action we are aware of doing, but do not concentrate on it our conscious abilities; we perform many quasi-conscious actions, such as walking, driving a car, etc.

available knowledge and information. They have often accompanied by an *enlightenment effect* (*heureka* or *aha effect*).

Let us recall that Simon [33] defined the essential phases of an analytical decision process to be *intelligence, design and choice*; later (see, e.g., [17, 38]), another essential phase of *implementation* was added. For creative or strategic, intuitive decision processes a different model of their phases was proposed in Wierzbicki [37].

- **Recognition**, which often starts with a subconscious feeling of uneasiness. This feeling is sometimes followed by a conscious identification of the type of the problem.
- **Deliberation or analysis**; for experts, a deep thought deliberation suffices, as suggested by Dreyfuses. Otherwise an analytical decision process is useful – with intelligence and design but suspending the final elements of choice.
- **Gestation**; this is an extremely important phase – we must have time for forgetting the problem in order to let our subconscious work on it.
- **Enlightenment**; the expected heureka effect might come but not be consciously noticed; for example, after a nights sleep it is simply easier to generate new ideas (which is one of the reasons why group decision and brain storming sessions are more effective if they last at least two days).
- **Rationalization**; in order to communicate our decision to others we must formulate verbally, logically, rationally our reasons. This phase can be sometimes omitted if we implement the decision ourselves[5].
- **Implementation**, which might be conscious, after rationalization, or immediate and even subconscious.

This process is not linear, recourse can occur after each of its phases. Especially important are the phases of gestation and enlightenment. Their possible mechanism relies on trying to utilize the enormous potential of our mind on the level of preverbal processing: if not bothered by conscious thought, the mind might turn to a task specified before as the most important but forgotten by the conscious ego. There exist cultural institutions supporting gestation and enlightenment. The advice of *emptying your mind, concentrating on void* or *on beauty, forgetting the prejudices of an expert* from Japanese Zen meditation or tea ceremony is precisely a useful device for allowing our subconscious mind work.

Intuition is mostly acquired by life-long learning and is preverbal, therefore, it is almost equivalent to tacit knowledge introduced by Polanyi [26]. Polanyi does not give fully rational definition of tacit knowledge (for example, he also stresses extrasensory aspects of it). On the other hand, the evolutionary rational definition of intuition has strong explanatory power, as discussed above. Because of this power, using this definition we can draw both theoretical and practical conclusions how to stimulate and better use tacit knowledge.

To illustrate this explanatory power let us discuss the issue of personal versus group tacit knowledge. From the rational theory of intuition outlined above it follows that we must formulate in words, rationalize our concepts or theories before communicating them to others. Thus, the classical discourse of Heidegger [11] about seven possible meanings of the words *nihil est sine ratione* can be supplemented by another meaning: *an intuitive judgment, by definition preverbal, must be rationalized when formulated, hence requires a ratio*. Another conclusion is as follows. If language was used as a tool of civilization evolution, individual thinkers were prompted to present their theories to the group, even to beautify and defend their theories – consistently with the Kuhnian concept of a paradigm. Such creative individuals might have been rewarded evolutionary, since eloquence might be considered as a positive aspect of mating selection. However, the evolutionary interest of the group that used the knowledge to enhance survival capabilities was opposite: too flowery personal theories and truth must have been considered suspicious, Popperian falsification was necessary. Thus, Popperian falsification and Kuhnian paradigm are two sides of the same coin.

The rational theory of intuition outlined here allows also various other practical conclusions. For example, when it comes to personal intuition, this theory implies that our best ideas for intuitive decisions might come after a long sleep, before we fill our mind with everyday life troubles. Hence a simple rule: put on your alarm clock twenty minutes before normal time of waking and try to find then solutions to your most difficult problems.

6. The concept of creative space

One of the main conclusions of the rational theory of intuition is that the old distinction between subjective and objective, rational and irrational is too coarse to describe the development of knowledge in times of informational civilisation. *There is a third, middle way: between emotions and rationality we have an important layer of intuition.*

Thus, we shall consider three layers of individual personality: *emotions, intuition, rationality*. We could also consider three layers of social human activity: *individual, group and humanity*, understood in the broadest sense because knowledge is heritage of all people. However, accepting three layers of human activity as well as three layers of individual personality would lead not to six as above, but to nine ontological elements of what we might call *creative space*. This leads to the following generalization of the SECI spiral

[5] The word *rationalization* is used here in a neutral sense, without necessarily implying self-justification or advertisement, though they are often actually included. Note the similarity of this phase to the classical phase of *choice*.

of Nonaka and Takeuchi: instead of four nodes of two-by two matrix, as represented in Fig. 1, we can consider nine *nodes of creative space*, as represented in Fig. 2, and diverse *transitions between nodes of creative space*.

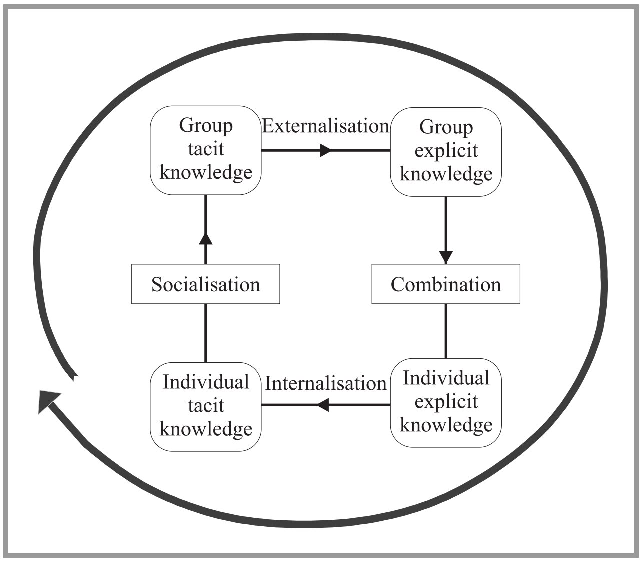

Fig. 1. A representation of the SECI spiral.

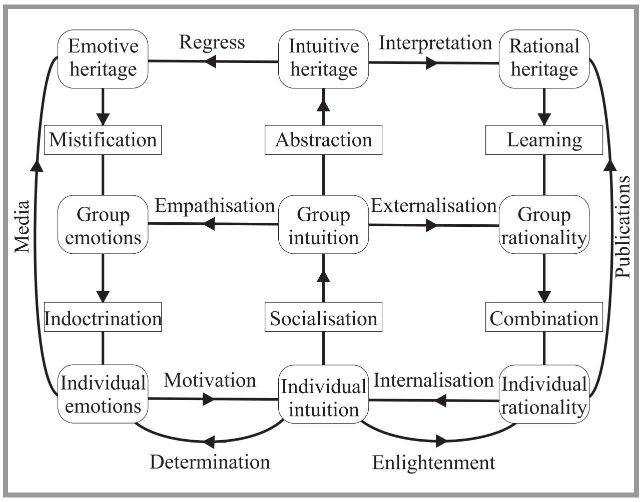

Fig. 2. Two basic dimensions of the creative space.

While the node *individual rationality* from Fig. 2 is almost equivalent to the node *individual explicit knowledge* from Fig. 1, the node individual tacit knowledge from Fig. 1 is subdivided into two nodes in Fig. 2: *individual intuition* and *individual emotions*. Similarly, the node *group explicit knowledge* from Fig. 1 is almost equivalent to the node *group rationality* in Fig. 2. However, the node *group tacit knowledge* from Fig. 1 is subdivided into two nodes, *group intuition* and *group emotions* in Fig. 2.

The nodes corresponding to emotions on all social levels include also instincts and myths; this is particularly important when we come to the third social level *humanity* in Fig. 2 that was not explicitly considered by Nonaka and Takeuchi. Yet this is a very important level, particularly in times of globalization, and playing an essential role in knowledge creation. The node *rational heritage* contains all experience and results of rational thinking – of science in its broad sense (including *hard sciences* – science and technology, *soft sciences* – humanities and history, but also *human sciences* – sociology, economy, law, medicine, etc.). It is in some sense similar to Popperian *third word*, but limited to its rational aspects. This heritage is recorded mostly in the form of books, but current informational revolution brought about here a change as important as the discovery (or re-discovery) of print by Gutenberg: change of recording medium to digital electronic records.

The emotive heritage consists of arts – music, paintings, but also literature, all fiction created by humanity, movies – that have only about a hundred year history, but recently became the main factor of trans-generational learning of emotive heritage. However, we can argue that this emotive heritage promotes also unconscious perception of *myths of humanity*. This is the concept of Jung [12] who called it *collective unconsciousness*, including in it also basic human instincts. Motycka [19] used this concept in her theory of creative behavior of scientists in time of scientific crisis or Kuhnian revolution: in order to have help in creating essentially novel concepts, scientists revert to the collective unconsciousness (Motycka called this *the process of regress*).

We do have also an intuitive heritage of humanity. Recall that Kant [13], following Platonian tradition, defined *a priori synthetic judgments* as our concepts and judgments of space and time that appear obviously true to us. Kant included in them the concept of space consistent with Euclidean axioms and the concept of time as used by Newton and other scientists before Kant. We know now that these concepts that seemed obviously true to Kant are not obvious and not necessarily true: space might be non-Euclidean, time might be relative or have several parallel scales, etc. Thus, these concepts are not a prior truth, although they seem to be true. How such preconceived ideas might be possible? A rational answer is – by intuition. We learn spatial relations when playing with blocks or Lego as children and such relations are the basis of our mathematical intuition; this intuition is strengthened by learning mathematics at school. Thus, the paradigm of teaching mathematics at school constitutes a part of the intuitive heritage of humanity. Our intuitive understanding of the world is not necessarily true, since our perception is mesocosmic, we do not often experience personally microcosmic and macrocosmic relations. But this mesocosmic perception gives us strong intuitive understanding of space and time, strengthened by the tradition of teaching mathematics. There might be other parts of the intuitive heritage of humanity – an intuitive feeling of logic related to quasi-conscious, intuitive use of language, etc. Note that this feeling is to a high degree learned, during debates in language lessons or in more advanced degree during formal training in logic. There are people that have better abilities of this intuitive feeling, there are also people that have better spatial intuition or time intuition. But there is no doubt that the intuitive heritage of humanity – including intuition for space, time, for logic – is one of the greatest achievements of our civilization.

Once we defined the ontology of nodes of creative space, we can discuss creative processes in terms of *transition between the nodes* of this space. Thus, between the nodes of *individual rationality* and *individual intuition* we might not only observe often the transition of *internalization* obtained mainly through learning by doing, as suggested by Nonaka and Takeuchi, but we can also observe sometimes the transition of *enlightenment* obtained by a creative intuitive process.

We cannot discuss here all nodes and transitions in detail that they deserve; but we shall outline shortly diverse conclusion resulting from the study of *creative space* together with its further dimensions, as suggested, e.g., by the I^5 *pentagram system* of Nakamori [22]. Beside *SECI spiral*, many other spirals of knowledge creation processes can be distinguished in *creative space*. These are:

- three spirals of organizational knowledge creation, typical for market-oriented organizations: oriental SECI spiral [24], occidental OPEC spiral [9], and brainstorming DCCV spiral [16];
- three spirals of normal academic knowledge creation, typical for normal scientific activities at universities and research institutes: hermeneutic EAIR spiral, experimental EEIS spiral, intersubjective EDIS spiral, that can be represented together in the triple helix of normal knowledge creation, all new and resulting from the concept of creative space;
- one spiral of revolutionary scientific creation processes: ARME spiral [19].

In order to shortly illustrate the tree spirals of normal academic knowledge creation processes, we present the *triple helix of normal knowledge creation* in Fig. 3, where a different graphic convention is used than in Figs. 1 and 2: small circles do not represent nodes, but transitions between nodes of *creative space*. These are the transitions: *enlightenment, analysis* (of all literature concerning the object of study), *hermeneutic immersion* (of the results of analysis), and *reflection* in the *hermeneutic EAIR spiral, enlightenment, experiment, interpretation* (of the experimental results) and *selection* (of conclusions) in the *experimental EEIS spiral, enlightenment, debate, immersion* (of the results of debate in intuition) and *selection* (of conclusions) in the *intersubjective EDIS spiral*. The triangles in Fig. 3 indicate the fact that individual researcher, having a new idea due to *enlightenment*, can switch between hermeneutic, experimental, intersubjective mode of research.

Finally, we shall shortly note importance of *computerized environments supporting creativity*. Nonaka stressed the importance of environment on creativity and introduced

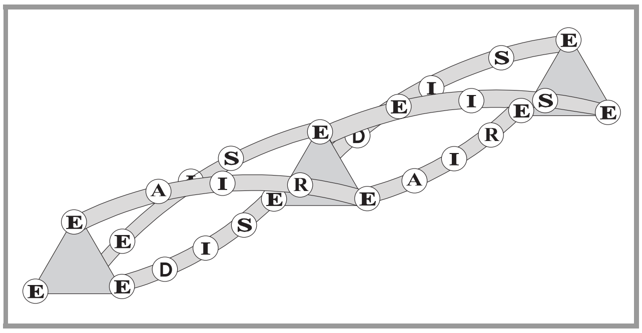

Fig. 3. Triple helix of normal knowledge creation.

the concept of *creative place Ba*. In times of informational civilization we should also use every technological possibility supporting creativity. There are many transitions in creative space and a general question might be formulated: *how to best support diverse creative transitions*? To specialists in multiple criteria decision support, there is no doubt that we can construct specialized creative environments, also for technology creation, similar to decision support environments. In particular, model-based decision support systems use the distinction between *preference model* and *core* or *substantive model*. While the former is subjective, individual, expresses the preferences of the decision maker, the latter is as objective as possible, summarizes relevant knowledge about a given decision situation. This distinction can be usefully transferred to environments supporting creative transitions between the nodes of creative space.

The discussion of this and related questions must be, however, postponed to other publications.

7. Conclusions

The conclusions of the paper are wide-ranging and we stress here only a few most important.

- Telecommunications and other informational sciences, in particular multiple criteria decision making, not only contributed the technological basis for the new era of informational and knowledge civilization, but also contributed significantly to the fundamental changes in perceiving the world characterizing the new era.
- Wittgenstein's statement [41] *"wovon man nicht sprechen kann, darüber muss man schweigen"*, though it makes a beautiful quotation, turned not to be true: we can speak today rationally about irrational metaphysical issues such as intuition and creativity.
- The science of industrial civilization era believed in the principle of reduction. We replace it today with the principle of the emergence of new properties with increased level of complexity.

- A picture is worth at least ten thousand words. This fact and an evolutionary thought experiment made it possible to formulate evolutionary rational definition of intuition and a rational theory of intuition.
- Tacit knowledge and its role in knowledge management can be analyzed in terms of the evolutionary rational definition of intuition that has a strong explanatory power.
- Language is only a code, simplifying the processing of information about the real world about 10^4 times. An absolutely exact, objective knowledge is not possible – not because human knowing subject is imperfect, but because he uses imperfect tools for creating knowledge, starting with language.
- The old distinction between subjective and objective, rational and irrational is too coarse. There is a third, middle way: between emotions and rationality we have an important layer of intuition.
- This three-valued logic and the recognition of importance of humanity emotive, intuitive and rational heritage lead to the concept of creative space, in which diverse creative processes might be considered, consisting of transitions between various nodes of this space.
- In particular, normal academic knowledge creation processes can be represented by a triple helix of normal knowledge creation.

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